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A study on different natural ventilation approaches at a residential college building with the internal courtyard arrangement

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Abstract

Dayasari RC is an old low-rise multi residential building which was established in the year 1966 and is located in the University of Malaya (UM) campus in the capital city of Kuala Lumpur. This building was designed with the internal courtyard that allows numerous implementations of bioclimatic design strategies, especially in regard of natural ventilation. Eight unoccupied student rooms were selected to represent ten different scenarios, where two from eight selected rooms had been chosen to represent two different scenarios. The scenarios are concerned with the level of radiation and penetration of sunlight that influence the values of temperature and relative humidity.

Different natural ventilation approaches were introduced simultaneously in all selected rooms for four weeks. Initially, the effectiveness of different ventilation approaches is obviously influenced by the position/floor level rather than the orientation of the selected rooms. The night ventilation is the most effective approach due to the lower mean temperature and higher relative humidity values. The recorded mean temperature values were below than 30°C with the relative humidity values exceeding 70%. Other ventilation approaches namely; daytime, full-day and no ventilation, were more than 30°C and had exceeded 32°C at certain rooms. The ranking of the effectiveness of the ventilation approaches was in the following order; Night ventilation > Daytime ventilation > Full-day ventilation > No ventilation.

Keywords: bioclimatic design, internal courtyard, natural ventilation, residential college building.

1. Introduction

The majority of people spend approximately 90% of their lives indoors, and indoor air pollution is one of the top four environmental risks to public health where the sources originate from combustion sources [1]. The indoor pollution is consistently reported to be around 2 to 5 times higher than outdoor pollutions [2]. This situation becomes more serious when there is inadequate ventilation in the house, either due to the design of the building itself or due to the actions taken by the occupants [3]. The lack of good indoor air quality has a strong bearing on the Sick Building Syndrome (SBS) where the main symptoms prevailing in SBS are headache, lethargy and dryness in body

mucus; mostly contributed by the concentration of CO_2[4]. The effects of the SBS will be more apparent with an increased CO_2 concentration.

The heat, ventilation and air conditioning (HVAC) systems are not the ultimate solution to these problems. These mechanical systems which are commonly used to control the temperature, humidity, circulation, ventilation and purification of the air in the building are not entirely the aspects which provide comfort to the building occupants. As reported by Yau [5], the majority of the occupants had been feeling uncomfortable from unpleasant odour resulting from the returning air circulation inside the building itself. This situation is a consequence of the design failure in HVAC systems in fulfilling the requirement of our distinctive hot and humid climates. Hence, natural ventilation is perceived to be the best approach in providing comfort to occupants [6-10]. The fluctuations of natural wind can make people more comfortable and closer to nature, while the prolonged low speed helps to reduce the feeling of tiredness, and intensifies the heat convection between people and the environment through the larger turbulence and intensity of natural wind [9]. The simulation predictions show that utilizing natural ventilation could help reduce air-conditioning energy use in the flats by about 24%, compared to the contrary [11]. The natural ventilation has a good potential in tropical and temperate climates but not in subtropical climate when the potential for comfort improvements in the hottest period (summer), is rather small [12].

Basically, shallow buildings with optimal orientation and a maximum of five floors is more applicable for exploiting wind for natural ventilation [13]. The inconsistent average wind speed and high air temperature that leads to stack effects become a major issue for natural ventilation in high rise buildings, especially an office building in a hot

and humid country [14]. Hence, natural ventilation in modern buildings is most common in residential buildings, schools and small office units [15].

Natural ventilation is highly variable and dynamic despite the fact that this approach is reliant on three principal factors, namely; the site and local landscaping features, the building form and building envelope, and the internal planning and room design [15]. In enhancing the convection and evaporative heat transfer between the occupants and the room air, five aspects should be considered to ensure the effectiveness of natural ventilation [8]. There are;

- **Spatial planning**, to allow air to move through from the windward side to the leeward side to create cross-ventilation.
- **Position of windows**, where at least two windows are placed on different external walls.
- **Ceiling height**, approximately 3m to allow air to flow vertically through the bottom of the window and it can diffuse through the room and out through the top of the window.
- **Size of windows** where there is a need for windows that open bigger or equivalent at the higher pressure opening as compared to the lower opening. Unfortunately, there is no guidance for the maximum size of the opening where other practical requirements such as sun control, security and privacy are to be considered [15]. According to Liping and Hien [16], the increase of the window to wall ratio to 0.24 can improve indoor thermal conditions to a large extent and horizontal shading devices are needed for the four orientations to further improve the indoor thermal comfort.

- **Types of window** that affect the volume of pressure and airflow pattern inside the building.

In addition, Tantasavasdi et al. [17] have listed measures that are needed to enhance the natural ventilation specifically for residential building [8, 15] in the list below;

- The natural ventilation should provide an indoor air velocity of 0.4 m/s as strong air movement can increase the rate of convective and evaporative heat loss from human skin to the environment.
- The total area of the inlet and outlet apertures should be about 40%.
- Avoid rectangular houses as they are not as good for natural ventilation as square-shaped houses
- Using larger inlet than outlet apertures (e.g. inlet area of $32m^2$ and an outlet area of $16m^2$).
- Keeping the indoor space as open as possible by reducing the number of walls inside the building, so that the wind can circulate freely.
- Closing the apertures on the east-facing and west-facing walls to avoid a shortcut.
- Keep long rooms in the east-facing part of the house.
- The elevated floor can allow more winds to flow through the houses and as an added advantage; a wind scoop on the ground level can be designed adequately.
- The buoyancy effect which can generate a maximum air speed of 0.25 m/s at the area close to a heat source.
- A ceiling fan can be used to increase the air velocity if the indoor air velocity is really low.

The application of mechanical devices such as the propeller fan and exhaust fan in the building is convenient for naturally ventilated buildings instead of air-conditioners to improve the indoor thermal conditions, especially in warm and humid regions [18]. There is only 45% of annual natural ventilation potential where the use of M&E is needed to support another 55% of ventilation [13]. There are three quite distinct uses for fans namely; to exhaust hot, humid and polluted air; to bring in outdoor air to either cool people or the building at night, and to circulate indoor air at those times when the indoor air is cooler than the outdoor air [10]. Cândido et al. [19] discover that the acceptable indoor air speed in hot humid climates should range between 0.2 to 1.5 m/s and when the operative temperatures exceed 24°C, air speed up to 1m/s is preferred by the building occupants. The ventilation rates can further be increased if the indoor air temperature is over 28°C to eliminate the heat [9]. However, the velocity along the body surface should not be over 0.8 m/s. Thus, natural ventilation must be done in an appropriate manner, as too much or too little outdoor air in a room can cause draughts and discomfort [20].

The aim of this study is to evaluate the condition of the selected rooms with different ventilation approaches by focusing on temperature and relative humidity. This residential college is an old multi-residential building and was designed with the layout of an internal courtyard. There are numerous implementations of bioclimatic design strategies which clearly demonstrate the sense of encouragement for air circulation in the room and building, at least in theory. Therefore, the best ventilation approaches will be revealed through the field measurement. Besides, the effectiveness of the recent adoption of bioclimatic design strategies in accommodating a comfortable room to the residents shall also be revisited.

2. Research design and approaches

2.1. Building description

The Dayasari Residential College (Dayasari RC) is an old low-rise multi-residential building with 18,212.51m^2 of total floor area and provides accommodation for 847 university students. This naturally ventilated building was established in 1966 and offers leisure areas, lounges, meeting rooms and laundry facilities. The typical room's floor area and volume are 16.35m^2 and 45.78m^3, respectively. The typical elevation and floor plan of Dayasari RC are presented in Fig. 1.

Fig. 1

There are numerous implementations of bioclimatic design strategies particularly on daylighting and natural ventilation [21].The building's orientation to the sun path is the north-south that reduces the glare and the thermal effect inside the rooms. For the west-east orientation, there are only service areas, such as toilets, bathrooms, stores, staircases and balconies. The building arrangement is based on the internal courtyard arrangement that provides daylight and natural air in the corridor and staircase areas. Furthermore, air circulation and daylight distribution are encouraged inside the room through the fixed transom on top of the entrance door and the wall. Indirectly, there is also an avoidance of the use of the corridor lamp during daytime; which is difficult to achieve at other residential college buildings due to their linear arrangement of the building layout [22]. Therefore, Dayasari RC has to be among the buildings with the lowest Energy Efficiency Index (34.52 kWh/m^2/year) compared to the other residential colleges; which are in the range of 40 to 125 kWh/m^2/year [23].

As part of the façade design of the building, there are two types of windows which are centre pivot and awning window with standard float and tinted glasses. The combination of operable window and fixed transom creates cross-flow/two sided ventilation. The installation of a wall-mounted centre-pivoting window in a bedroom significantly improves the indoor air quality by increasing the efficiency of the natural ventilation [24]. Thus, this type of window represents a crucial element in the design of sustainable buildings.The window to wall ratio (WWR) is 0.66 with 6.41m^2 of the window area and the operable window area is only 4.20m^2 with 0.43 of an operable WWR. The WWR is not efficient when on the current update, the ASHRAE 90.1 Standards Committee had voted 0.24<WWR<0.40 for low-rise buildings [25]. In order to reject the undesirable amount of solar radiation, there are large horizontal overhangs along the window in each room to give a significant shadow effect to the rooms. In addition, there is wall opening in the room that theoretically helps to create wind pressure inside the room. The fixed transom, wall opening in the room and façade design of the residential building are presented in Fig. 2.

Fig. 2

Unfortunately, the large horizontal overhangs along the window are not available in the room on the ground floor. Therefore, green landscape with high diversity of plants should be well adapted to reduce the thermal and glare effects from the maximum sunlight penetration especially in the mid-afternoon [26, 27]. As an old residential college building, most of the plants are well matured with the huge canopies capable enough to cover the ground and give a shading effect to the building. There are 61:39 ratio of soft and hard landscape area with 0.607 of the Biotope Area Factor [28].

2.2. Microclimate of UM campus

As it is located in the equatorial region, the UM campus has a typical tropical climate, little seasonal variation with a constant annual average. The climate is hot and humid all year around with uniform temperature and high humidity. It is extremely rare to have a full day with a completely clear sky; even during periods of drought, and a stretch of a few days with completely no sunshine except during the northeast monsoon seasons. Moreover, the UM campus is only affected by the weaker Southeast monsoon from April to September and winds are generally light.

The annual temperature profile of the UM campus for the period of 1981 until 2009 is presented in Fig. 3 and Table 1; in which there are uniform temperatures throughout the year.

Fig. 3

Table 1

Annually, the mean temperatures are in the ranges of 26.3°C and 27.6°C as documented in the year 1984 and 2006 respectively. The daily range of temperature is large; from 8°C to 12°C, when the days are frequently hot and the nights are reasonably cool everywhere. Referring to Fig. 4, mean relative humidity varies between 74.3% and 87.0% when the minimum was in 2004 and the maximum was in 1991, as shown in Table 2.

Fig. 4

Table 2

2.3. Field measurement

The rooms and residential building by the residential college administration have limited accessibility due to the privacy and safety issues. Accordingly, the area had been restrained and some period of time predetermined for the field measurement to be carried out. Therefore, eight unoccupied rooms which are the most excellent in representing the ten scenarios were selected for the field measurement; where two from eight selected rooms had been chosen to represent two different scenarios. The ten identified scenarios are concerned with the level of radiation and penetration of sunlight into the rooms that influence the values of temperature and relative humidity. All scenarios are well described in Table 3.

Table 3

Two parameters which are temperature (°C) and relative humidity (%) were recorded by using ONSET HOBO U12-012 data logger for four weeks as permitted by the residential college administrators. This data logger was set to cover a 24-hour period with a one-hour interval between measurements at 1.10m above the floor [29]. This height is acknowledged as the typical human body level. One data logger was fixed in the middle of the room for indoor measurement and at the outside of the selected rooms for the examination of outdoor climates, specifically in the corridor area. The location of the field measurement and the two data loggers are shown in Fig. 5.

Fig. 5

The accuracy of data loggers fixed in the selected rooms and the corridor area is ±0.35°C from 0° to 50°C and ±2.5% from 10% to 90% relative humidity, to a maximum of ±3.5%.

Different ventilation approaches were introduced simultaneously in all selected rooms as described below;

1. Daytime ventilation: All the operable windows were kept open from 8 a.m. until 7 p.m. From 7 p.m. to 8 a.m., all operable windows were kept closed.
2. Night ventilation: All the operable windows were kept open from 7 p.m. until 8 a.m. From 8 a.m. to 7 p.m., all operable windows were kept closed.
3. Full-day ventilation: All the operable windows were kept open 24 hours daily.
4. No ventilation: All the operable windows were kept closed 24 hours daily.

The curtains were kept open while the doors kept closed as the measurement took place. Therefore, the effectiveness of different ventilation approaches in influencing the temperature and relative humidity of the selected rooms will be revealed holistically. Additionally, the recent adoption of bioclimatic design strategies in accommodating a comfortable room to the residents will also be highlighted.

All the collected data were initially analysed using the Hoboware pro software. Further descriptive statistical analysis of temperatures and relative humidity in all eight selected rooms which representing ten different scenarios; including the corridor areas, was done by using a statistical computer software package [30, 31]. This further analysis was done to obtain the mean, max and min values according to the ventilation approaches which were introduced simultaneously in all selected rooms. Thus, the effectiveness of each natural ventilation approach and numerous implementations of

bioclimatic design strategies in accommodating a comfortable room to the residents will be revealed quantitatively.

3. Results and discussion

The mean values of the temperature and relative humidity with different ventilation approaches in eight selected rooms with the different scenarios are presented in Table 4, while visualised through charts shown in Fig. 6 and Fig. 7.

Table 4

Fig. 6

Fig. 7

By analysing the Table 4 horizontally, the effectiveness of four ventilation approaches in reducing the indoor temperature was influenced by the position and the scenario that was represented by the selected rooms. The night ventilation had effectively reduced the indoor mean temperature in the room which represents scenario W3 (direct contact with man-made surfaces on the top), scenario B1/B4 (north orientation/avoid direct contact with man-made surfaces on the ground), and W1 (east orientation). There are in the range of 1°C to 2°C of a difference as compared to other ventilation approaches namely daytime, full-day and no ventilation. The percentages of relative humidity are much higher when the differences are up to 8%. According to Kubota et al. [31] the application of night ventilation at residential buildings can provide better thermal comfort due to high humidity conditions that reach 70-80% of indoor relative humidity and decrease indoor surface temperatures by up to 3.9°C [32]. Thus, this type of

ventilation decreases the building cooling load up to 40 kWh/m^2/year, with an average contribution that is close to 12 kWh/m^2/year [33, 34]. The efficiency of night ventilation is strongly related to three main parameters namely the relative difference between indoor and outdoor temperatures, air flow rate and the thermal capacity of the building [35].

In the rooms that depict scenario B2 (south orientation), W2 (west orientation), B3/W5 (avoid direct contact with man-made surfaces on the top/Exposed) and W4 (direct contact with man-made surfaces on the ground), the effectiveness of night and full-day ventilations is obviously similar when the same mean temperature values were recorded. However, the implementation of the full-day ventilation drastically reduced the percentage of relative humidity, in the range of 3% to 4%. Initially, both night and full-day ventilation approaches were much better as compared to the other two approaches namely; daytime ventilation and no ventilation. The mean temperature values were 1°C higher, while the mean percentages of relative humidity were much lower as compared to the night and full-day ventilation. The full-day ventilation can provide better thermal comfort for hot-humid climate, and non-insulated construction materials with thermal mass inertia are the ideal choice for naturally ventilated buildings in hot-humid climate [16]. The full-day ventilation would be a better option as compared to night ventilation in reducing the operative temperature during the afternoon in Malaysia, while the ceiling insulation with window shading devices were applied as part of the building design [31].

The daytime ventilation reduced the mean percentages of relative humidity in all rooms as compared to the no-ventilation approach. Apparently, there were no differences in the mean temperature values in all rooms with the implementation of

daytime ventilation and no ventilation; except in the room which represented scenario W3. Without any ventilation, a higher mean temperature was recorded in this room. As the room is located on the top floor of the building, the highest mean temperature and the lowest percentage of mean relative humidity values were recorded with the implementation of all ventilation approaches. The radiation on a flat roof is greater than that on the vertical wall [36] and more than 40% of the solar gain is through the five-storey block of flat's roof [37]. Meanwhile, higher temperature was recorded at the top level of flats and apartments compared to the ground floor which is more affected by heat penetration from the ground and tarmac, especially when there are no trees with large canopies around [38].

Different situations had been recorded in a room which represented scenario B5 (shaded by landscape or trees). The mean temperature values were still 29°C even though different ventilation approaches were implemented. The variations were only seen on the mean percentages of relative humidity. The mean percentage of relative humidity which was recorded in this room with the implementation of night ventilation was the highest, as compared to the other rooms and ventilation approaches. Therefore, landscape with the green plants is able to improve the indoor environment by sustaining the indoor climate, although different ventilation approaches were implemented by the residents. In turn, for W5 (exposed to open spaces), the mean temperature increased 1°C with the implementation of daytime and no-ventilation approaches. The tree canopy provides shading and insulation effects to reduce the conductive heat gains while preventing unpleasant solar to penetrate into the building [26, 39]. Additionally, it captures more latent heat and reduces air temperature by promoting more evapotranspiration especially in the tropical climate regions [37, 39-

41]. Hence, it improves the air quality especially in urban areas [42]. According to Konya and Vandenberg [43], most unpleasant results are translated into placing paved surfaces which store up a great deal more heat, exceeding 50% of the radiation and remain hot longer than unpaved or grass surfaces which only store 5% of the heat. The concrete paving, white walls and reflective glazing can all reflect intense solar radiation into a window [10].

Focusing on the effectiveness of ventilation approaches in providing better condition in the room, the indoor mean temperature and relative humidity values were compared with the values that had been recorded in the corridor area (Fig. 6 & 7). Generally, the mean indoor temperature values of the selected rooms were similar, or were 1 to 2°C lesser as compared to the corridor through the implementation of daytime and full-day ventilation approaches. The highest mean values which were recorded in the room and at the corridor with the implementation of both ventilation approaches were 29°C and 30°C, respectively. Furthermore, the percentages of relative humidity in the rooms were much higher as compared to the percentages of relative humidity at the corridor. The differences were in the range of 1 to 6%.

On the contrary, the mean temperature values were higher in the selected rooms as compared to the values which were recorded in the corridor area with the implementation of the night ventilation. There are two rooms that represented scenario W2 (west orientation) and B5 (shaded by landscape or trees). Even though the values were still small (below than 30°C), with regards to the mean percentages of relative humidity, the differences between the indoor and corridor are only in the range of 1 to 2%. The highest percentage was 72% which was recorded at the corridor of the room which represented scenario B5. The same condition was also recognised with the

implementation of no ventilation approaches. The mean indoor temperature values were much higher as compared to the corridor, especially in the room on the top floor. With the higher temperature, not much difference in the percentages in relative humidity was identified between the indoor and the corridor, where the percentages were only in the range of 1 to 3% with the highest percentage of both areas only 69%.

4. Conclusions

The effectiveness of different ventilation approaches in a multi-residential building is obviously observed. The effectiveness of the ventilation types is influenced by the position/floor level rather than the orientation of the selected rooms. The room at the top floor has shown numerous mean values of the temperature and relative humidity with the implementation of different ventilation approaches.

The presence of green landscape provides a better environment in the surroundings, in the building, as well as in the room. Lower mean temperatures with a higher percentage of relative humidity were recorded in the rooms which are shaded by a big canopy of trees as compared to the rooms which are exposed to open spaces. Additionally, the condition of the shaded room was maintained despite the different ventilation approaches implemented. Only small changes of the relative humidity values were discovered.

The daytime and full-day ventilations would be able to provide better indoor conditions by reducing the temperature in all selected rooms. Different conditions were observed with the implementation of night and no-ventilation approaches when the indoor temperature was higher as compared to the corridor in some of the selected rooms. However, night ventilation is the most effective approach due to the lower mean

temperature values. The recorded mean temperature values were below than 30°C, whilst other ventilation approaches namely; daytime, full-day and no-ventilation, were more than 30°C and exceeding 32°C at certain rooms.

Consequently, the ranking of the effectiveness of ventilation approaches in a multi-residential building; which is designed with an internal courtyard of building arrangement and numerous bioclimatic design strategies, is in the following order;

Night ventilation > Daytime ventilation > Full-day ventilation > No ventilation

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